Impact of Slab Thickness on Reinforced Concrete Buildings using Fragility Curves

Nirav K. Patel, Sandip A. Vasanwala

Abstract: ***Earthquakes are the natural disaster occurring since years but during the last two decades they are causing huge looses whether it may economic or to life. This paper focuses to evaluate the seismic performance of various building confirming to Indian standard criteria for earthquake resistant design of structures and ductile detailing of reinforced concrete structures subjected to seismic Forces-code of practice, Bureau of Indian Standards, both as per the revised codes in the year 2016. Due to ground shaking, seismic loads are the governing load and thus it becomes necessary to assess the conditional probability of structural response. Use of HAZUS methodology is followed to construct seismic fragility curves as it is well-organized and defined approach. Spectral displacement plays the functional parameter to derive the expected damage for fragility. This work represented here is compiled by means of procedure for establishing the fragility curves for three typical Reinforced Concrete (RC) frame structures having variations resembling 3 storey intended for short-period structures, 6 storey used for medium-period structures and 12 storey representing long-period structures using SAP2000 as a software tool for analyzing the structure. Furthermore an attempt is made for focus on the variation of one of the major structural configuration i.e. slab thickness which is not certainly paid attention as compared to columns and beams. Slabs adds additional stiffness to the structure which can enlighten how it behaviour would be when subjected to ground excitation. As a result, the fragility curves are plotted to study the impact due to slab thickness in order they are carefully selected while design.***

Keywords: capacity spectrum, Reinforced concrete, slab elements, Hazus methodology, seismic fragility curve.

I. INTRODUCTION

Reinforced concrete buildings in a range of 2 to 12 storey constitute the major part of the infrastructure. Ample deficiencies are there in concrete structures which are calculated neglecting various seismic considerations, for instance wide spacing of shear reinforcement, insufficient force transfer between the horizontal and vertical components of the lateral system and discontinuity of reinforcement in slabs and beams. Consequently it is important to evaluate the seismic performance of typical reinforced structures and estimate their seismic fragility to foreshow the probability of damage in future seismic events.

The development of fragility curve is needed so as to know the probability of any particular damage state. The damage state intensity varies as slight (S) relatively minute, moderate (M) which is quite reasonable, extensive E) and maximizing collapse (C) about to crumple.

To propagate the fragility curves, numerous approaches can be used which can be grouped like empirical methods based on past earthquake surveys, judgmental method based on expert opinion and experience, analytical based on equations and hybrid using a combination of above mentioned methods. The preferable and widely used are the analytical approaches due to its simplicity along with the efficiency of generated data, while the empirical ones has a drawback as they are more specific to a definite site condition resembling to the one being studied. Calvi et al [6], has done an intensive study on various methodology and also meant that estimation of loss assessment is done through HAZUS globally.

The method used for loss estimation due to earthquake is commonly known as HAZUS. As per HAZUS®MH MR5 [9], the damage functions due to any seismic activity have two necessary components: (i) capacity curves and (ii) fragility curves. Capacity curves are plotted with help of technical parameters such as strength at its yield and ultimate points so as to correspond to the Non linear Static Pushover Analysis (NLSPA), while the fragility curves represents the probability to what extend any damage has occurred to the structure.

HAZUS methodology has is used to plot the lognormal probability distribution function as per shown in (1). In addition to it, attention is to given as the distribution may not all the time be the best fit as per HAZUS®MH MR5 [9].

$$P_f\,(ds/S_d) = \varphi\left[\frac{1}{\beta_{ds}}.\ln\left(\frac{S_d}{\bar{S}_{d,ds}}\right)\right] \quad (1)$$

Pf () is probability of being at or exceeding a particular damage state (d_s) for spectral displacement (S_d) plotted using ϕ as the standard normal cumulative distribution function; β_{ds} is standard deviation of the natural logarithm of spectral displacement and median value of spectral displacement at which the building reaches the damage-state, ds is denoted by $\hat{S}_{d,ds}$.

II. MODELING AND ANALYSIS

As majority of the structures constructed nowadays are of Reinforced Concrete, the material of members are kept viewing so. When analyzes is to be governed by lateral load, ductility plays a major role and thereby implementing the provisions as per amendments given in recent version of BIS. The frames are analyzed and modeled using Structural analysis program (SAP2000) [12] as a software tool.

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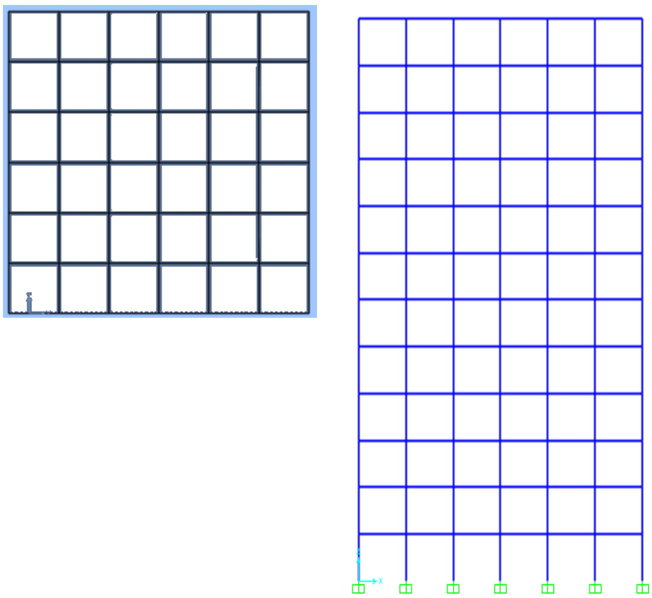
A. Geometry configuration

The plan configuration is kept as a symmetric square shape with varying its story level so as to cover all range i.e. short, medium and long period structures. The other important parameters are as described in Table I.

Table -I: Basic parameters and input data

Sr. No.	Description	Detailing
1.	Type of structure	RCC
2.	Number of stories	3, 6 & 12
3.	Bays in x & y Direction	6
4.	Bay span	4 m
5.	Typical Storey Height	3 m
6.	Height of Buildings	9m, 18m, 36m
7.	External wall thickness	230 mm
8.	Internal wall thickness	115 mm
9.	Slab Thickness	0.1m, 0.15m, 0.2m
10.	Floor Finish	1 kN/m^2
11.	Impose load	3 kN/m^2
12.	Concrete Grade	M 25
13.	Steel Grade	Fe 415
14.	Type of soil	Medium Soil
15.	Importance factor	1.2
16.	Seismic Zone	IV
17.	Zone Factor	0.24
18.	Response Reduction factor	5

A typical 12 storey building view is as shown in Fig. 1.



(a) (b)

Fig. 1. Typical view of a 12-storey building: (a) Plan, (b) Elevation

B. Structural Configurations

The chosen structural design is based on Indian codal provisions BIS 456 [3] in addition to BIS 13920 [4]. Moreover all the beams and columns have given common section size throughout the whole floor. Besides the column sections are reduced for every three storey in order to lessen unnecessary dead load. As per requirement of ductile detailing and the best practices of strong column weak beam the Reinforce Concrete section details are given in Table II.

Table II: Member details

Frame Storey	Floor	Column		Beam		
		Size (mm)	*Long. Reinf.*	*Size (mm)*	*Bottom Reinf.*	*Top Reinf.*
3	1 to 3	300 x 300	12-Φ20	250 x 450	2-Φ16	4-Φ16
6	1 to 3	400 x 400	12-Φ25	250 x 450	2-Φ20	4-Φ20
	4 to 6	400 x 400	12-Φ16	250 x 450	3-Φ16	5-Φ16
12	1 to 6	550 x 550	12-Φ25	300 x 600	3-Φ16	4-Φ20
	7 to 12	550 x 550	8-Φ20	300 x 600	3-Φ16	4-Φ20

C. Structural Configurations

Beams and columns are preliminary analyzed and performing design checks are revised as and when required while on the other end slabs are not given that due importance. Consequently, keeping rest parameters including loading as constant, altering the slab thickness to focus on its behaviour when subjected to ground excitation. Using the data as per table I and table II, the weight are computed along with fundamental time period as recommended in BIS 1893[5], to determine the base shear as represented in Table III.

Table III: Base shear for RC frames considered

Frame Storey	Ht. (m)	Td (s)	Sa/g	W (kN)	Slab thickness (mm)	Ah	Vd= W.Ah (kN)
3	9	0.389	2.50	2838	100	0.06	170.30
				3153	150		189.20
				3468	200		208.10
6	18	0.655	2.00	6295	100	0.048	302.14
				6925	150		332.38
				7555	200		362.62
12	36	1.102	1.25	15351	100	0.030	460.54
				16575	150		497.26
				17799	200		533.98

D. Nonlinear Static Pushover Analyses

The guidelines for the NSPA are specified in ATC [1]. According to study of Krawinkler and Seneviratna [10] the internal actions computed at these target displacements are been utilized to derive the strength and deformation demands. Discrete plastic hinges are assigned to the beams and columns so as to check which exceed their elastic limit. SAP 2000 gives the right to allocate hinges along the element at any position for this analysis. The provisions of FEMA 356 [7] are been incorporated for assigning the plastic hinge properties in SAP 2000. Plastic hinges are assigned considering M3 for beams and P-M2-M3 for columns. Furthermore, the default hinge properties can also be chosen as per ATC-40 [1] criteria.

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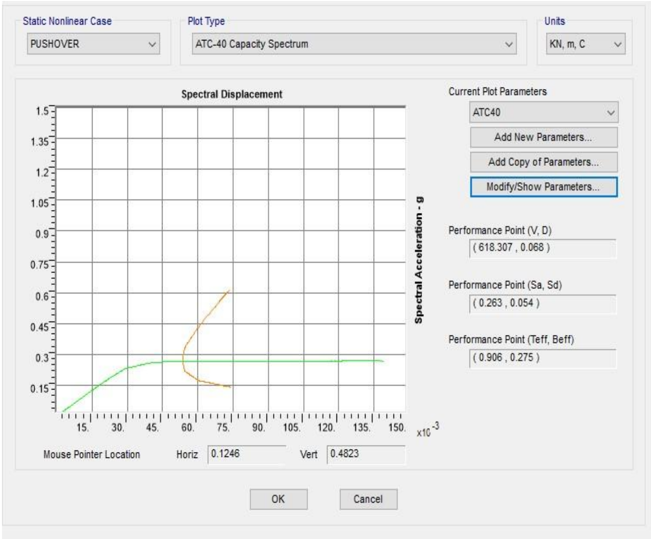
E. Estimation of Performance point

During the ground shaking, as per the intensity felt and the health of the structure, it will hold any one of the damage state. The NSPA is performed using numerous load combinations to plot the capacity curve as well as demand curve to arrive to the performance point of the structure by means of capacity spectrum method for the RC building, as shown in Fig. 2.



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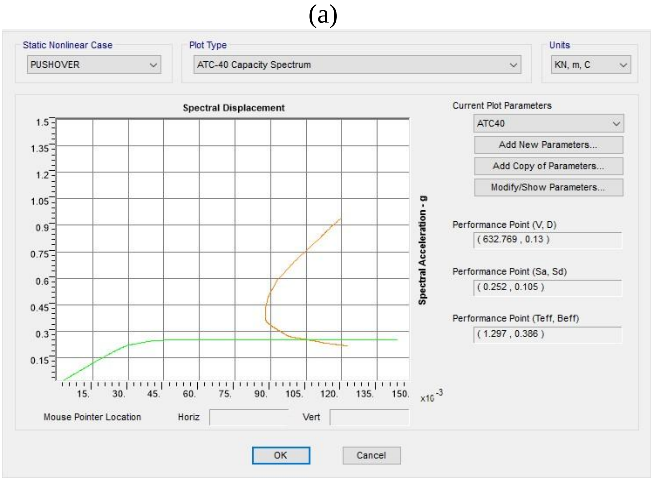

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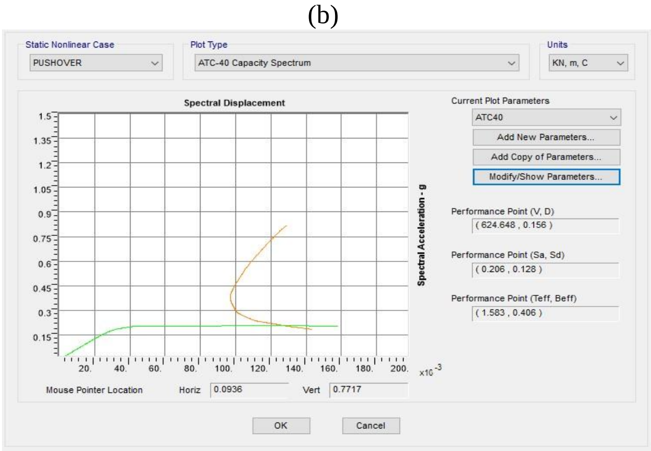


(c)

Fig. 2. Capacity Spectrum and Performance point for 3-storey buildings, slab thickness:(a) 100 mm, (b) 150 mm, (c) 200mm

F. Control Points

Based on the capacity spectrum obtained, important points called as control points at yielding level and maximum level are to be extracted from it. Yield capacity control points defined as yield displacement (D_y) and yield acceleration (A_y) are established at the point where significant yielding begins while the ultimate acceleration (A_u) is extracted as the upper limit point of spectral acceleration in terms of strength before attaining its entire plastic capacity. Ultimate displacement (D_u) is selected as either the spectral displacement corresponding to (2) or the highest value obtained from the corresponding value of spectral displacement at the point of highest spectral acceleration. Table IV shows the value of control points of all storey buildings considered with its slab thickness.

$$\mathrm{Du} = 2\,\mathrm{Dy}\frac{\mathrm{Au}}{\mathrm{Ay}} \quad (2)$$

Table IV: Summary of Control Point

Storey	Control Points	Slab Thickness		
		100 mm	*150 mm*	*200 mm*
3 S	(D_y) m	0.030	0.030	0.032
	(A_y)	0.200	0.200	0.180
	(A_u)	0.270	0.280	0.210
	(D_u) m	0.138	0.147	0.158
6 S	(D_y) m	0.040	0.040	0.050
	(A_y)	0.150	0.150	0.145
	(A_u)	0.210	0.185	0.165
	(D_u) m	0.175	0.200	0.250
12 S	(D_y) m	0.035	0.035	0.035
	(A_y)	0.075	0.060	0.060
	(A_u)	0.090	0.090	0.090
	(D_u) m	0.320	0.340	0.340

G. Damage state Threshold $\hat{S}_{d,ds}$

The value of damage state threshold for various states is calculated using Barbat A. H, Pujades L.G., and Lantada N. theory [2] and is given in a tabular format in Table V.

Table V: Damage State and Respective Ŝd,ds values (mm)

Slab Thick-ness	Damage State	$\hat{S}_{d,ds}$	3 Storey	6 Storey	12 Storey
100 mm	Slight	0.7 D_y	0.021	0.028	0.025
	Moderate	D_y	0.030	0.040	0.035
	Extensive	D_y + 0.25 (D_u - D_y)	0.057	0.074	0.106
	Collapse	D_u	0.138	0.175	0.320

150 mm	Slight	0.7 D_y	0.021	0.028	0.025
	Moderate	D_y	0.030	0.040	0.035
	Extensive	$D_y + 0.25\,(D_u - D_y)$	0.059	0.080	0.111
	Collapse	D_u	0.147	0.200	0.340
200 mm	Slight	0.7 D_y	0.022	0.035	0.025
	Moderate	D_y	0.032	0.050	0.035
	Extensive	$D_y + 0.25\,(D_u - D_y)$	0.064	0.100	0.111
	Collapse	D_u	0.158	0.250	0.340

H. Damage state Variability β_{ds}

In this study, Damage State variability and capacity variability are taken moderate as 0.4 and 0.3 respectively while the value of degradation factor (Kappa factor) as 0.9 (Minor), 0.5 (Major), 0.1 (Extreme), 0.1 (Extreme), corresponding to Slight, Moderate, Extensive and Collapse, ds respectively. Thereby arriving to values of total β_S parameter projected as per Table VI. The values are inputted from FEMA HAZUS®MH MR4 [8]. It has noted that as storey raises the total β_S value decreases.

Table VI: β_S Parameter

Damage State	Slight	Moderate	Extensive	Collapse
C1L (3 storey)	0.8	0.95	1.05	1.05
C1M (6 storey)	0.75	0.85	1.0	1.0
C1H (12 storey)	0.75	0.85	1.0	1.0

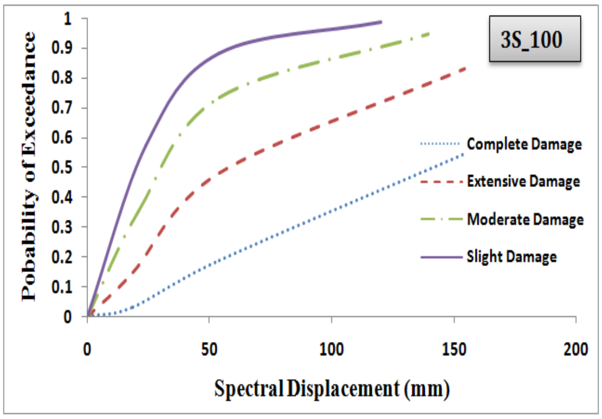
I. Fragility Curve development

Various damage states at performance point are computed and its Cumulative Probability is found out using (1) for and is tabulated in Table VII. The fragility curves are plotted in Fig. 4 for all stories with various slab thickness.

Table VII: Cumulative Probability of Building Type

No. of storey	*Slight*	*Moderate*	*Extensive*	*Collapse*
3S_100	0.881	0.732	0.479	0.186
3S_150	0.978	0.906	0.707	0.374
3S_200	0.985	0.928	0.748	0.421
6S_100	0.905	0.767	0.578	0.297
6S_150	0.964	0.873	0.644	0.308
6S_200	0.956	0.856	0.618	0.283
12S_100	0.942	0.828	0.332	0.061
12S_150	0.971	0.890	0.557	0.191
12S_200	0.986	0.930	0.751	0.423

Note: *Here 3,6 and 12 are storey; 100, 150 and 200 are slab thickness in mm*



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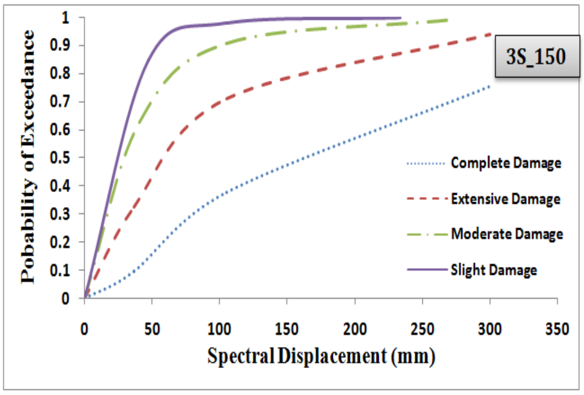

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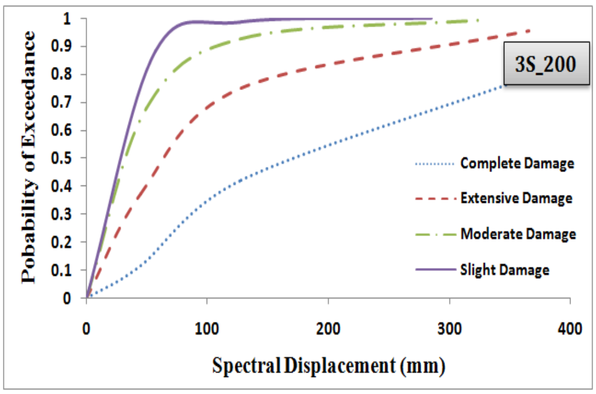

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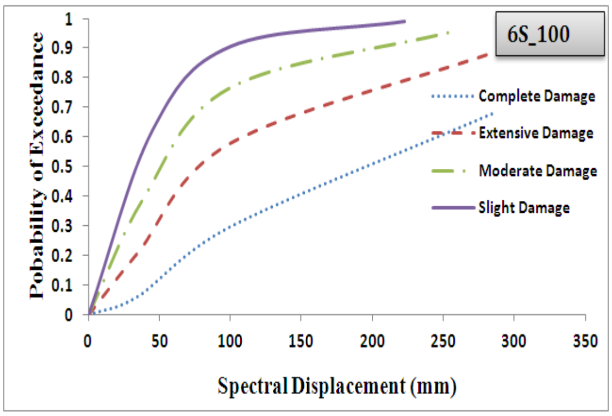

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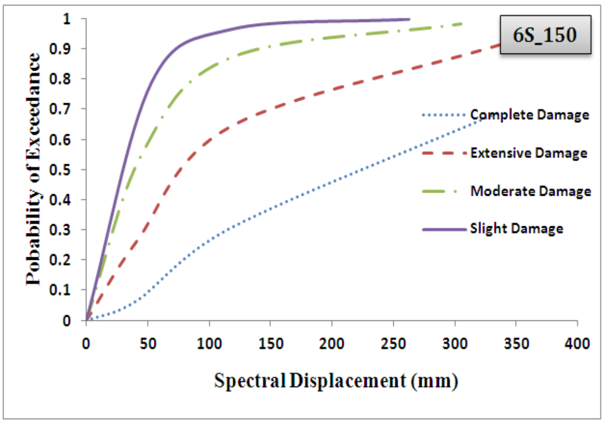

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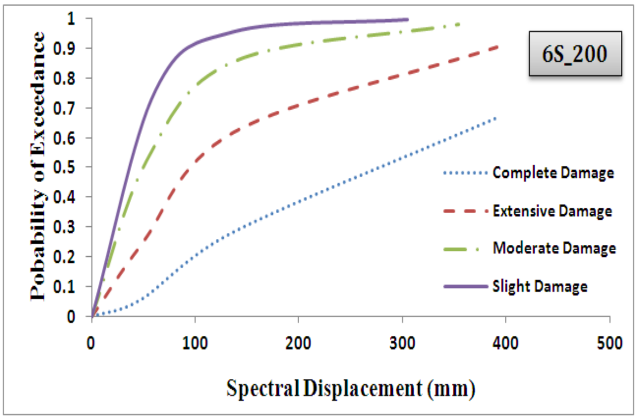

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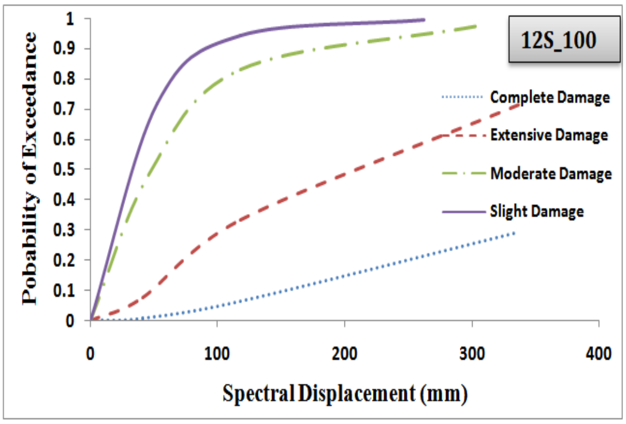

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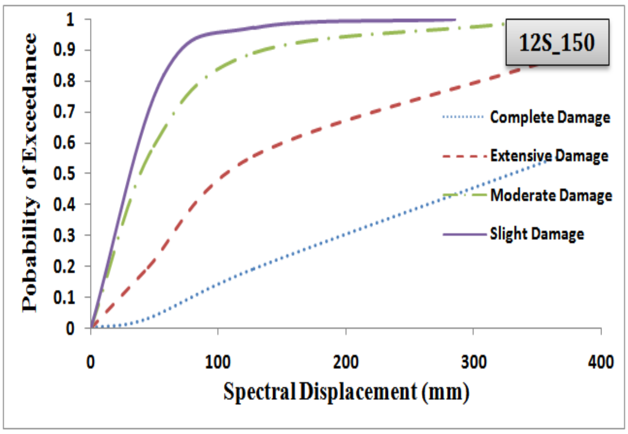

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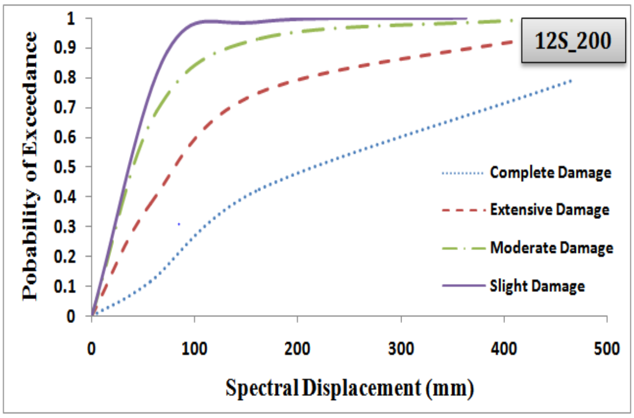

(i)

Fig. 4. Fragility Curves showing damage states for buildings (a) 3-st. 100 mm, (b) 3-st. 150 mm, (c) 3-st. 200 mm
(d) 6-st. 100 mm, (e) 6-st. 150 mm, (f) 6-st. 200 mm
(g) 12-st. 100 mm, (h) 12-st. 150 mm, (i) 12-st. 200 mm

III. CONCLUSIONS

According to the study carried out for evaluating the performance of buildings followings points are noteworthy:

- This methodology gives an idea to anticipate the damage level of building related to a particular value of spectral displacement.
- Structures with lower levels are more at risk for slight or moderate damage state.
- As the number of storey increases, the possibility of occurrence of damage state also increases.
- The probability of moderate damage and extreme damage is more in each class as compared to slight and collapse damage.
- Focusing on fragility curves for slight d_s and moderate d_s, the 12 story are quite close together, while the 3 story and 6 story curve shows a considerable difference.
- Due to increase in the slab thickness, the rigidity of the structure also increases which can be analyzed by increase in base shear and reduction in maximum displacement.
- As slab thickness, the damage level for collapse state also increases, while it reversed for moderate damage state which indicates lower slab thickness tends to moderate damages when attracted to lower seismic forces.

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